

Heavy ion sputtering of solid and liquid Sn

M.D. Coventry, R.A. Stubbers,
& D.N. Ruzic

*Plasma-Material Interaction Group
University of Illinois @ Urbana-Champaign*



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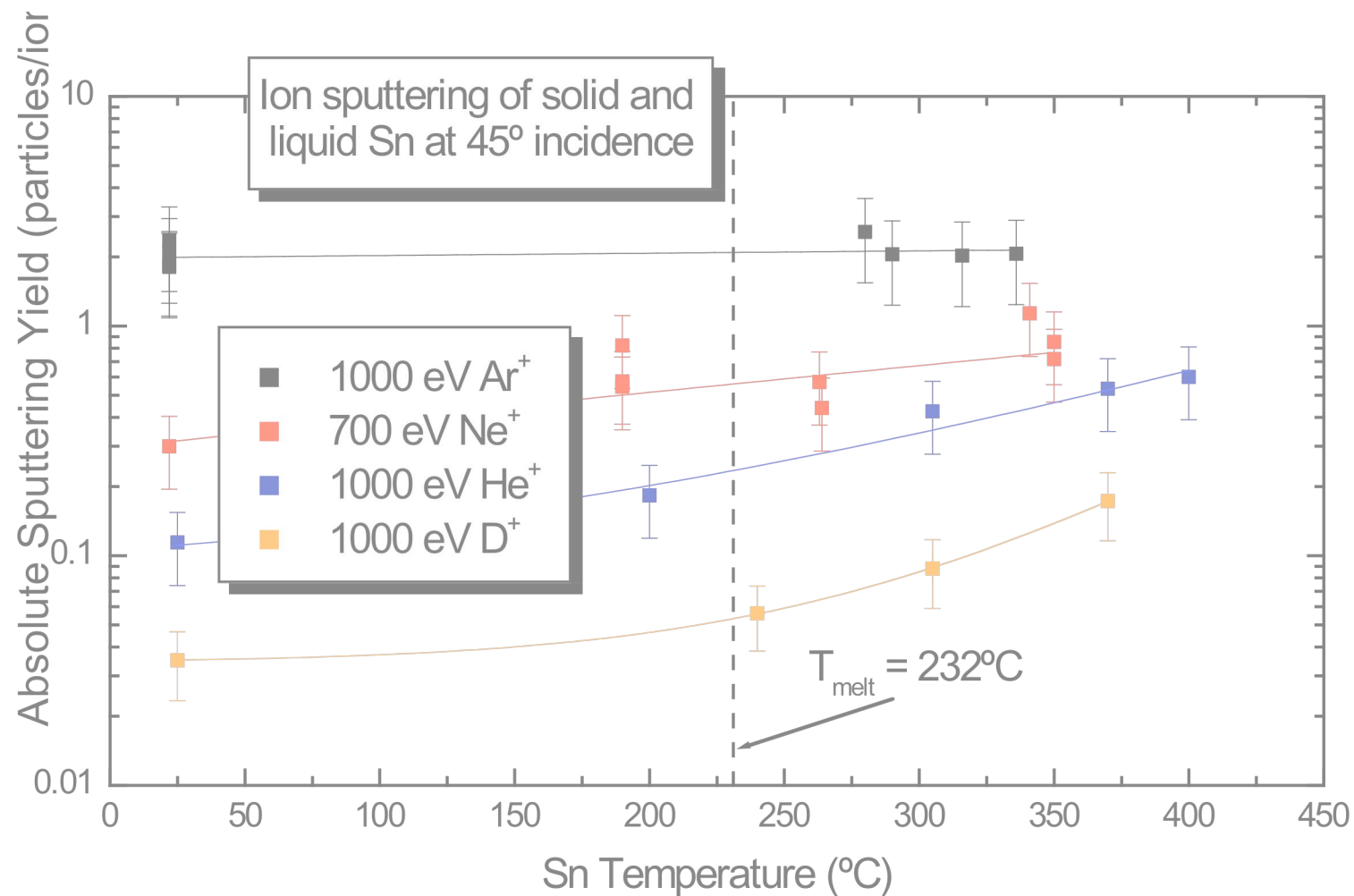
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Outline

- Sn sputtering work using IIAX
 - Summary of light & heavy ion bombardment
 - Sn ion source
- IIAX experimental modifications
 - Completed
 - In progress/planned
- Future work

Sn sputtering results from 4 species



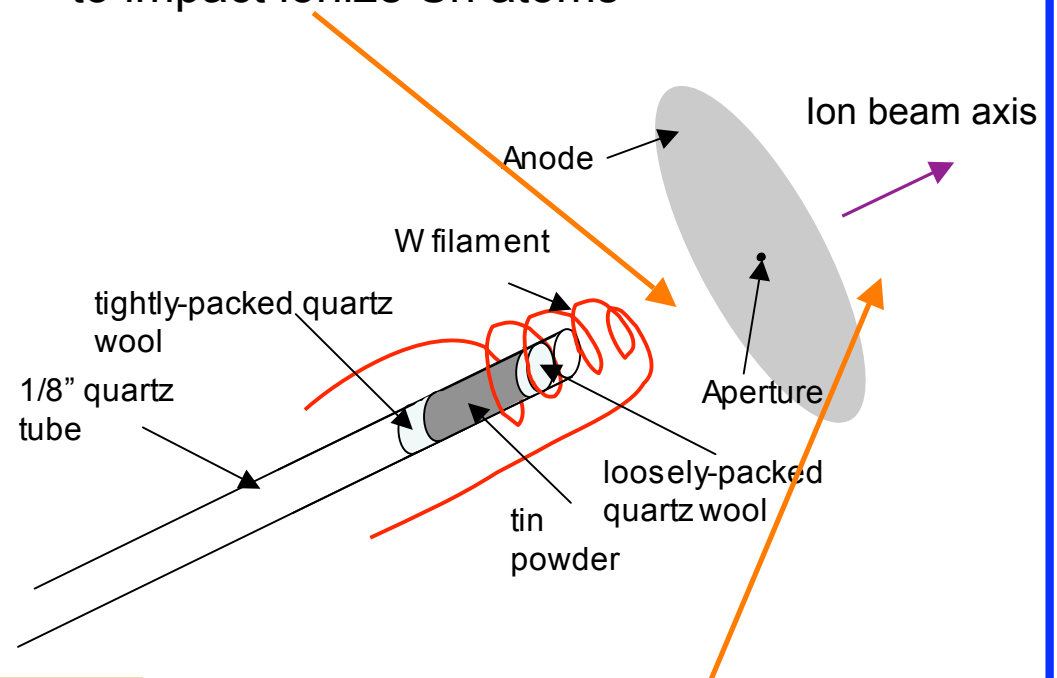
Move to Sn self-sputtering

- Sputtering yields are needed to model liquid Sn divertor more accurately
- Hopeful that self-sputtering has little or no temperature dependence
 - This would allow Sn divertor design the most flexibility in operating temperature (limited to $\sim 1200^\circ$ in evaporation-limited case)
 - Evidence of reduced temperature-dependent sputtering behavior for heavy ion bombardment of Sn
- Trouble: Lack of experience generating a Sn^+ beam
 - While the Colutron ion source in IIAX is made to supply numerous varieties of ion species including Sn, it is not necessarily easy to obtain them on a consistent basis like the gaseous-source beams

Sn ion source

- Same as gaseous ion source except a solid charge holder is inserted within the windings of the coil to vaporize material
- An Ar discharge assists in producing Sn ions for extraction
- A Wien filter is used down the beam line to filter out Ar ion components of the beam

Ar gas discharge between filament (cathode) and anode provides electrons to impact ionize Sn atoms

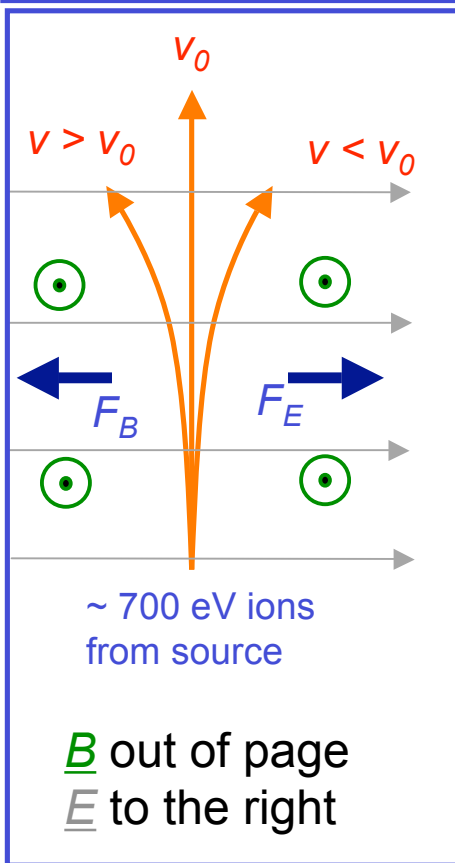


Construction based on conversations with Dr. Lars Wåhlin from Colutron (Ion gun mfr.)

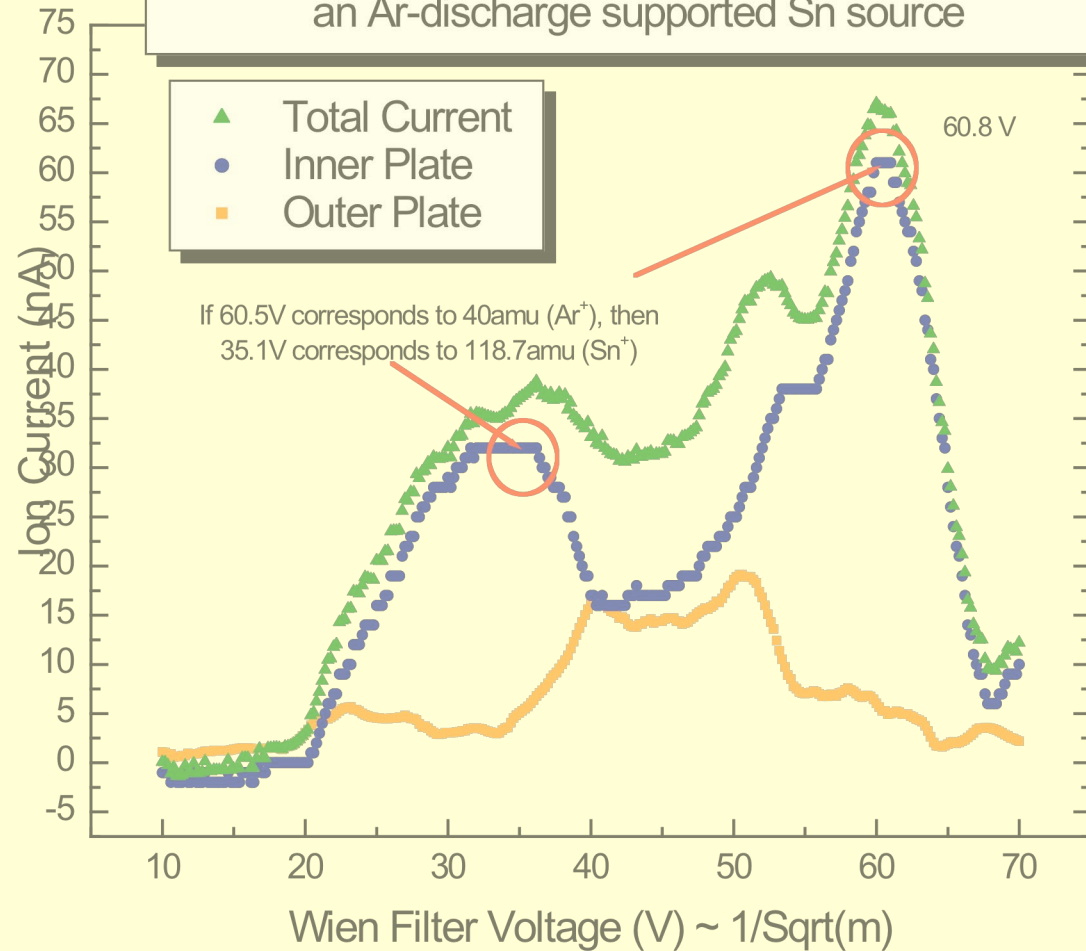
Extraction / acceleration region followed by ion filters & optics

Sn⁺ component identification

Wien filter

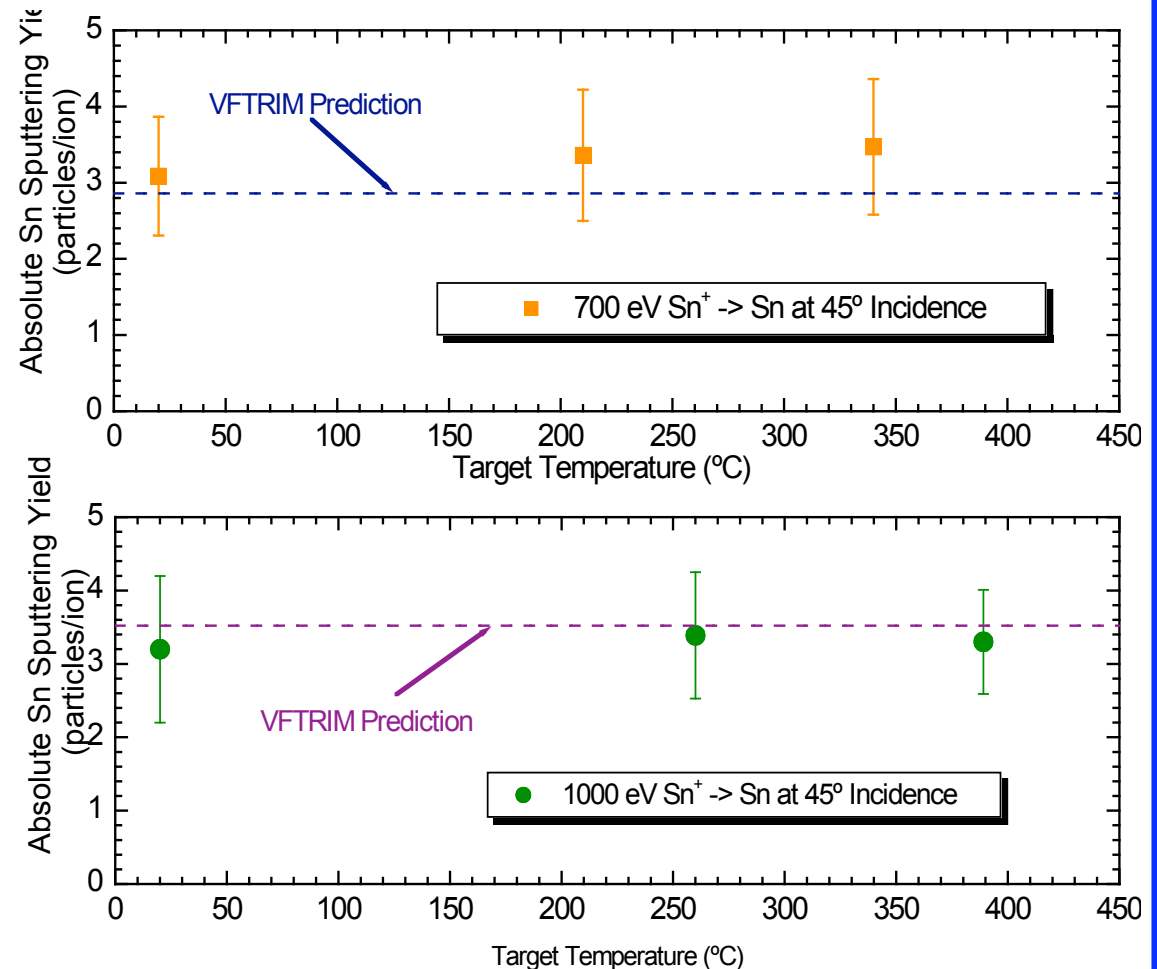


Velocity spectrum of 1000 eV ion beam extracted from an Ar-discharge supported Sn source



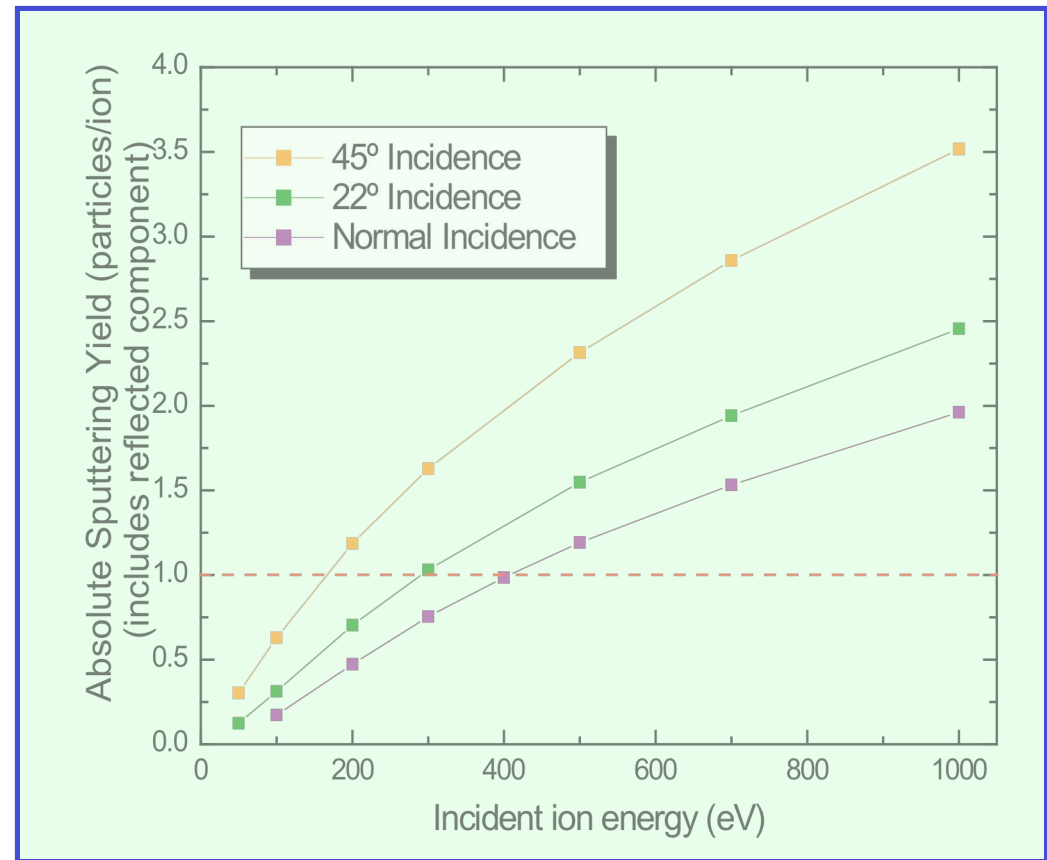
Sn self-sputtering measurements

- Early data indicate that Sn self-sputtering is also not significantly enhanced by temperature at least up to 400°C
- These results are similar to those for both Ne⁺ and Ar⁺ sputtering of Sn (from a temperature enhancement perspective)
- Important to note that higher temperatures may still yet show temperature-enhanced properties



VFTRIM Simulations of Sn self-sputtering

- Sn ions are predicted to have a mean incident angle of 22° [1] for an ARIES-AT configuration with a liquid Sn divertor
- Thus, equally important is the reduction from decreasing the angle of incidence
- Normal-incidence runs may be performed in the future to complement the oblique work done here



[1] Brooks, J.N. Fus. Eng. Des. **60** (2002) 515-526.

Modifications / Improvements

- Data analysis improvement
- Horizontal control planned but is currently obtained by target manipulation
- Vertical control after second Einsel Lens
- Planned or in progress

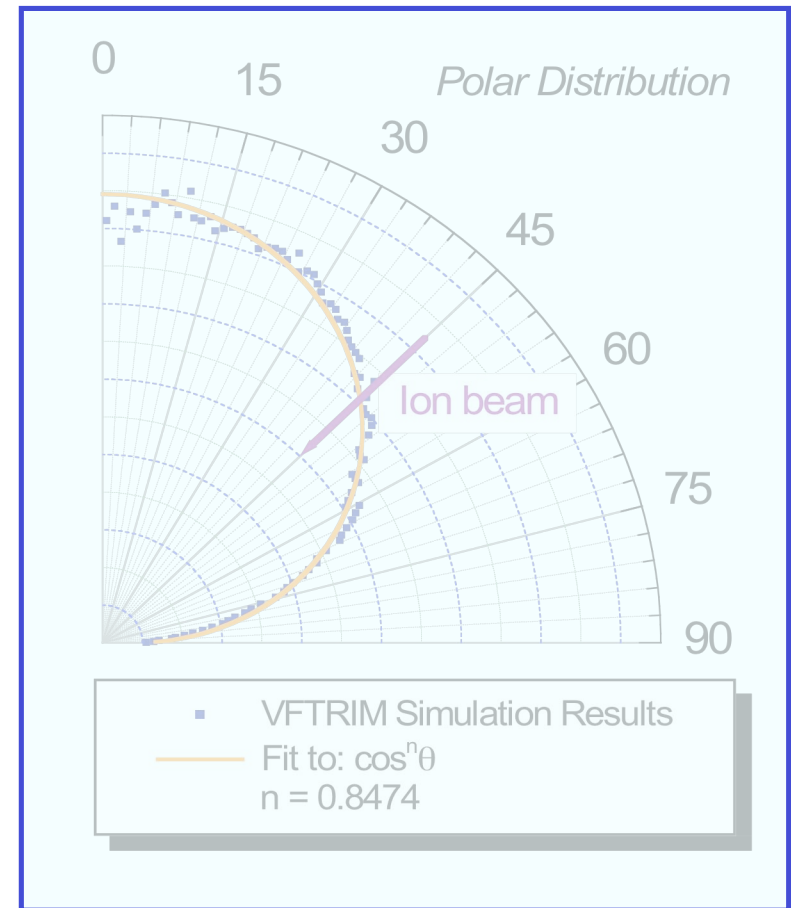
Improved estimate of “geometric factor”: 1

In general...

- This “geometric factor” is just an integral over the QCO crystal surface that estimates what fraction of the sputtered material strikes (but not necessarily sticks to) the crystal
- VFTRIM simulations are now performed for each ion-target combination to generate sputtered particle distribution “data” to input into the computation of this geometric factor

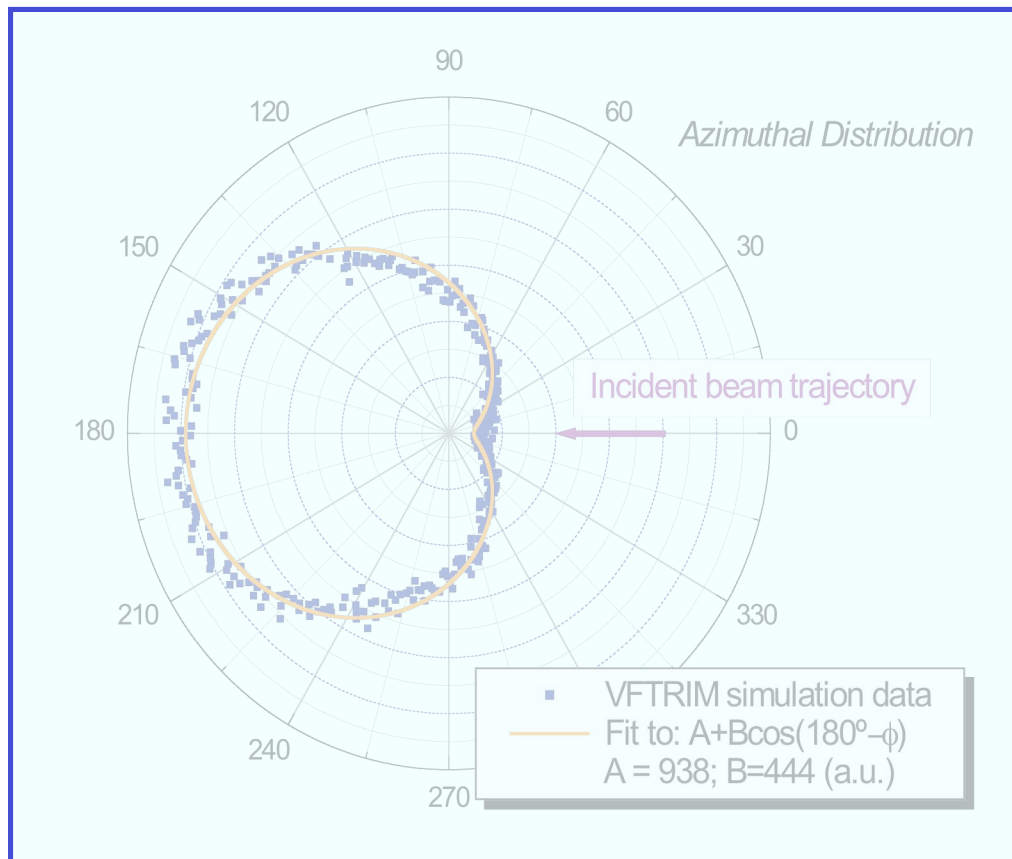
(Polar angle)

- A and n are fit such that $A \cdot \cos^n \theta$ fits the VFTRIM polar “data”
- Previously assumed $\cos^1 \theta$ polar distribution – This correction of n made little difference in the final result



1000 eV $\text{Sn}^+ \rightarrow \text{Sn}$
at 45° incidence

Improved estimate of “geometric factor”: 2



1000 eV $\text{Sn}^+ \rightarrow \text{Sn}$
at 45° incidence

(Azimuthal angle)

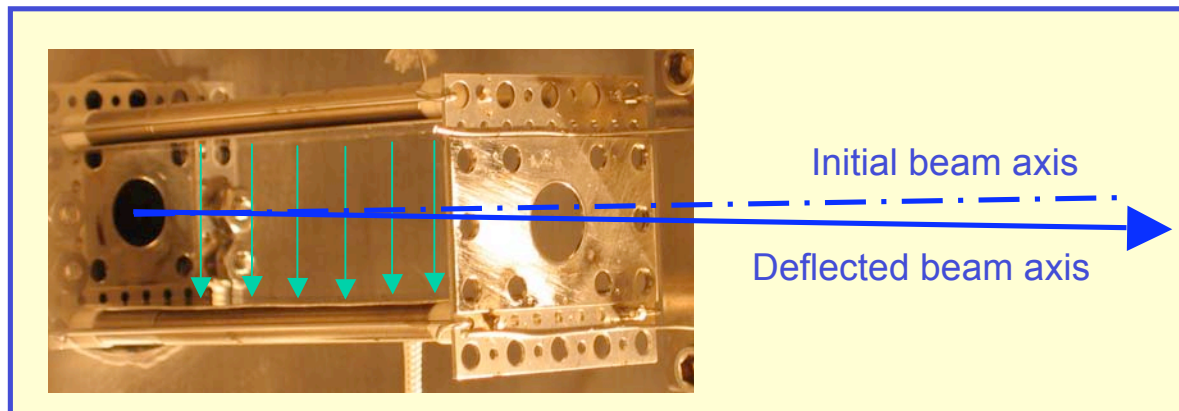
- Previously assumed azimuthal isotropy
- Significant anisotropy due to oblique incidence
- Parameters A and B are varied using $A + B \cdot \cos(\phi - \pi)$ to fit VFTRIM azimuthal distribution “data”

(NOTE: This function is just a guess that fits most data sets well and so doesn't necessarily have a physical interpretation)

Ion beam optics modifications 1:

Horizontal deflection plate pair installation

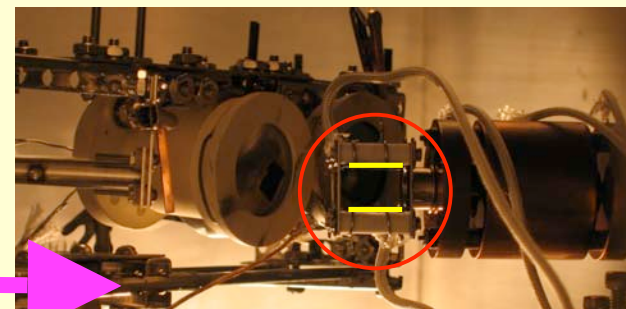
- Installed horizontal deflection plates to make 3° bend to filter neutrals
 - Previously relied on Wien filter \underline{E} -field to bend beam followed by 10 – 15 cm of 3.5-cm diameter tubing (along unbent beam axis)
 - Now, horizontal deflection for neutral filtering is performed after entering the main chamber
 - Result of upgrade: Reduced beam degradation (more beam current reaches target)



Ion beam optics modifications 2:

Vertical deflection plate pair installation and translation of final optics

- Installed vertical deflection plates following ion decelerator
 - Improved final steering before striking target
 - Horizontal steering provided by target translation (for now)
- Closed final optics-to-target gap from ~ 10 cm to ~ 2 cm
 - Focus here was to improve strength of lower energy beams (< 300 eV)
 - Especially important for heavier (slower) ion beams to minimize space-charge losses following final optics



In the pipe...

(modification-wise)

- High target temperature-enabling steps
 - Repairing QCO head for electrically-isolated water cooling
 - Redesign of target / heater holder to minimize heat loss
 - Smaller volume → Reducing thermal mass & water cooling will help local system reach thermal equilibrium when sample temperature is changed
 - Much less surface area for emission
 - Reduced thermal contact with holder
 - Goal: Reach 1000°C (Heater rated for 1200°C)
- Lower ion energy work
 - With reduced distance from second Einzel lens (focusing element), in addition to the final ion optics lying only 1 cm from the sample space charge losses should be greatly reduced
 - Goal: strong 100 eV beam for various ion species)

Summary

- Progressing on collection of Sn sputtering data with focus on self- and heavy ion sputtering
- The sputtering yields of heavy ion bombardment of liquid Sn doesn't seem to show any temperature dependence, at least at the energies and temperatures considered here.
- Significant upgrades to beam optics to improve both quality and quantity of beam reaching the target
- Modifications in progress include those to increase the sample temperature and to allow lower ion energies – both make our measurements more relevant for a Sn divertor

Future Work

- Upgrades:
 - *Horizontal deflection plates for rastering*
 - *Target holder modification for changing angle of incidence (perhaps just normal and 45° incidence options to start)*
- Near-term:
 - *Focus on heavy ion (including Sn) of liquid Sn at lower energies and higher temperatures*
- Big picture for 2005+
 - *Temp. dep sputtering of liquid Sn & Ga*
 - *Li⁺ or Sn⁺ sputtering of Mo & LM-coated Mo*
 - *Measurement of the ionized fraction of sputtered material of PFC*
 - *Mixed **solid** material sputtering relevant to ITER (W, Be, C, etc.)*

Acknowledgements

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